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NEW DIGITAL GOVERNOR IMPROVES SPEED CONTROL AT AN ISOLATED PLANT, ALLOWS FOR INTERCONNECTED ELECTRICAL SYSTEM

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ABSTRACT

The Tyee Lake Hydroelectric Plant, owned and operated by The Four Dam Pool Power Agency (FDPPA) in Anchorage, Alaska, consists of two 11.25 MW impulse turbine units. The plant is part of an electrical system in the island archipelago of southeast Alaska and is the primary generation source. The peak load of the system is approximately 11 MW. Previously, the performance of the system's mechanical governors had been poor, with minor load variations sending the governor into unrecoverable oscillations. The original Woodward UG-HT governors also had no provisions to support rapid load acceptance. To aid with system stability, diesel turbines would often be operated, resulting in additional fuel and personnel costs to the utility.

In spring 2006, L&S Electric, Inc., (Rothschild, Wis.) replaced the mechanical governors with a digital-hydraulic governor solution designed around commercially available components. The new governors allow flexible operation of the system, providing needle sequencing, automatic underfrequency detection, water waste mode capability and integrated automatic synchronization. The new digital governors have stabilized the system, routinely managing load rejections of 2 to 4 MW. The controls respond much more quickly and predictably, without the need to constantly adjust the governors or turn on expensive diesel generators. Most importantly to FDPPA, the improved control offered by the new governors means completion of a 57-mile long, 138-kV transmission line between the Tyee Lake plant and the neighboring Swan Lake Hydroelectric Plant is feasible. The "Swan–Tyee Intertie," will allow access to power generated at Tyee Lake by the city of Ketchikan, which often uses diesel-generated power because the Swan Lake plant doesn't generate enough hydroelectric power. Ketchikan will save approximately $135 million in diesel fuel costs over 30 years at today's prices after the interconnection is complete. Without the new governors, the intertie wouldn't be possible. When completed, the Swan-Tyee Intertie will be only the second interconnected electrical systems in the state of Alaska, and the first in the FDPPA system.

INTRODUCTION

The entire population of the state of Alaska is 663,661, yet in area, the state is more than twice the size of Texas. Six of Alaska's 10 most populous cities have less than 10,000 residents. In a state this large, communities exist in remote locations, many accessible only by air and sea. This is the case for the cities of Wrangell and Petersburg, which are situated on islands in southeast Alaska and have a combined population of just over 5,000 people. Although remote, both cities are self-sufficient with economic activity primarily related to timber and forest products and commercial fishing and seafood processing. Providing power to its businesses and residents is the Tyee Lake Hydroelectric Plant located on the mainland of Alaska, approximately 40 miles southeast of Wrangell. The Tyee Lake plant is the region's main source of renewable power and is supplemented by a small hydro plant outside Petersburg and some diesel generators that are used when the plant is unavailable due to maintenance or repair activities. A system of

power grids and transmission lines, things most residents in the lower 48 states take for granted, don't exist in Wrangell or Petersburg.

The Tyee Lake power plant utilizes twin, vertical shaft, six-jet Pelton impulse turbines driving 11.25 MW generators. There is no dam at the plant. Rather, a lake tap intake draws water from Tyee Lake. From the intake, there is a drop shaft, an 8,300-foot long, 10-foot diameter unlined power tunnel and a 1,350-foot long steel penstock bringing water to the powerhouse.

Approximately 70.5 miles of 138-kV transmission line and 11.4 miles of submarine cable interconnect the Tyee Lake plant to the communities of Wrangell and Petersburg where the power is utilized. Access to the plant is by plane or boat only and there is a small harbor for boat or barge access.

Prior to 2006, Wrangell and Petersburg experienced an average of one complete blackout per month because the system's mechanical governors and servomotors were unable to respond in a stable manner to any type of load disturbance. For example, if an eagle flew into a transformer they would lose the whole system and both towns would go dark.

Slow governor response, long transmission lines and highly capacitive submarine cable components combined to make it very difficult to bring the system back on line if there was an outage. When the system went down, operators had to bring the load up gradually to ensure that the system didn't go down again. During an outage, planned or otherwise, operators resorted to the diesel-powered generators to provide power to the towns. Diesel generation represents the most costly power supply resource for the towns. Not only is it expensive for the municipalities to use diesel power, but all fuel has to be brought in by boat or barge.

THE FOUR DAM POOL POWER AGENCY

The Tyee Lake Hydroelectric Plant is owned and operated by The Four Dam Pool Power Agency (FDPPA), a non-profit wholesale generation and transmission utility. FDPPA is a joint action agency made up of three municipalities, (Ketchikan, Petersburg and Wrangell, and two electric cooperatives, Copper Valley Electric Association, Inc. (CVEA) and Kodiak Electric Association, Inc. (KEA). The electric utilities of the cities of Ketchikan, Petersburg and Wrangell provide electric service within their respective communities. CVEA provides electric service to the greater communities of Valdez and Glennallen and the Copper River Basin. KEA provides electric service in and around the cities of Kodiak and Port Lions. FDPPA owns three other hydroelectric generating plants in addition to the Tyee Lake plant. These facilities include the Swan Lake Hydroelectric Plant (Ketchikan), Solomon Gulch Hydroelectric Plant (Valdez) and Terror Lake Hydroelectric Plant (Kodiak). FDPPA also owns and operates the transmission lines that connect the generating plants to the electric systems of the member utilities. All of the plants were commissioned by the state of Alaska from 1982-1985 and in 2002 were sold to the newly-created FDPPA.

The Thomas Bay Power Authority, which was created by the cities of Petersburg and Wrangell, operates the Tyee Lake plant. Aside from the Petersburg-Wrangell connection, none of the electric systems of the FDPPA member utilities are connected with each other. They all are electrically isolated from any other electric utility system.

Although energy sales from Tyee Lake are in the range of original expectations, connected loads in Wrangell and Petersburg have been, and continue to be, significantly lower than the generation capability of the plant. As a result, in 1998, the city of Ketchikan began design of and permitting for a 57-mile long, 138-kV transmission line between the Tyee Lake and Swan Lake plants — the "Swan–Tyee Intertie" — that would allow access to power generated at Tyee Lake by the city of Ketchikan. This project became the responsibility of FDPPA in 2003.

In addition to greater utilization of the energy generation capability of the Tyee Lake hydroelectric plant, a significant benefit of the Swan–Tyee Intertie will be the interconnection of the Ketchikan, Wrangell and Petersburg electric systems. Integrated operation of the facilities will improve overall utilization of the available hydroelectric resources. In addition, the intertie will provide the ability to backup hydroelectric generating units in the system with other hydroelectric units, thereby improving system reliability. Unit maintenance also can be more effectively scheduled and accomplished with an interconnected system. The state of Alaska recognized the value of the intertie and provided FDPPA with a grant to replace the governors through the Denali Commission, a federal-state partnership designed to provide critical infrastructure throughout Alaska.

The Swan–Tyee Intertie also will serve as a significant component of a proposed Southeast Alaska electrical transmission system. In the future, it will provide for long-term benefits in the ability to develop Southeast Alaska's significant hydroelectric potential on a more cost-effective regional basis rather than on a community-by-community basis. The state currently is evaluating a transmission intertie with BC Hydro, which operates the largest electric system in British Columbia, Canada. This interconnect would be made at the Tyee Lake plant, further opening hydro development opportunities for Alaska.

AN INTERCONNECTED SYSTEM

As inconvenient and expensive as it was to run the diesel-powered generators, what really drove FDPPA to replace the mechanical governors at the Tyee Lake plant was its desire to construct the Swan-Tyee Intertie. The difficulties in sharing loads between the two plants would have been compounded by the existing governors. FDPPA knew that they must have governors at the two plants that were compatible in order for the plants to pick up and share load and maintain the system frequency. Therefore, the agency made the decision to replace the mechanical governors at the Tyee Lake plant to ensure compatibility after completion of the intertie.

FDPPA awarded the contract to replace the mechanical governors to L&S Electric, Inc., of Rothschild, Wis., a system integrator with extensive experience in the hydroelectric power generation industry. L&S Electric was evaluated as the lowest risk solution because the company already had similar control applications and equipment running in hydroelectric plants in the Pacific Northwest. This was a major factor in the decision to hire the system integrator since the power provided by Tyee Lake was critical to Wrangell and Petersburg. The only power available to these small communities was what they could generate on their own. Given the isolated environment, L&S Electric was able to offer FDPPA the assurance that the governors would perform with its proposed system.

The contract was awarded to L&S Electric on October 31, 2005. Logistically this was one of the worst times of the year since the system integrator had to contend with winter and early-spring wave problems, high winds and highly variable tides. The contract specified that work on the first turbine had to be completed by

July 1, 2006 because the utility needed power from both of its turbines to provide electricity to canneries during the summer months. Therefore, downtime of any kind during this period was not an option and work could not resume until after Labor Day. Unlike other companies that responded to the request for proposal, L&S Electric exceeded FDPPA's schedule requirements by opting to complete work on both units by July 1.

GOING DIGITAL

L&S Electric proposed replacing the mechanical governors with a digital-hydraulic solution designed around commercially available components, in particular a control system based on the Telemecanique® brand Modicon® Quantum™ programmable logic controller (PLC) from Schneider Electric. The PLCs were programmed with the Unity™ line of development software. L&S Electric also specified Telemecanique brand Magelis® XBT-GT graphic touch screen terminals.

The digital governor solution provided a host of benefits to FDPPA, not the least of which are improved response characteristics and performance. The new system also allowed for a reduced parts count, fewer spare parts and offers better reliability because of fewer failure points. In addition, the spare parts that are required are less expensive because they are commercially available through Schneider Electric distributors around the world. The digital governor system also gives maintenance personnel the ability to easily determine where a fault has occurred because it incorporates built-in diagnostic tools and alarms. With the mechanical governors, it was difficult to identify the cause of a fault, or in some instances, even to recognize that a fault had occurred until there was a major failure. Repair time for problems also is shorter with the digital governor system. In addition, the PLC platform utilized offers the ability to add unit control function to the governor or to integrate the governor with a unit controller.

In continuing with its philosophy to provide a commercially available solution, L&S Electric kept the existing hydraulic pressure system and opted to use off-the-shelf hydraulic control valves with individual control loops for each needle servomotor. These control valves replaced the custom-made, proprietary, mechanically-linked valves previously used for servomotor control. In the past, if the Tyee Lake plant needed a valve, the part was fabricated new every time. With the plant's remote location, FDPPA wanted to make new parts as accessible as possible. Many turbine components were designed in Switzerland, so the agency didn't want to compound the problem by having more difficult-to-obtain parts available from only one supplier.

IMPORTANCE OF THE CONTROL ALGORITHM

A major component of the project for L&S was providing FDPPA with advanced control modes in the control algorithm. Speed sensing, regulation and stabilization of the governor system is accomplished through this digital control algorithm and electronic circuits that provide signals used to control the turbines.

One of the advanced control modes L&S Electric included was the ability for the governors to control the deflector and needle servomotors virtually independent of each other. If the needle nozzles either open or close too quickly, they can create excessive pressure transients in the water tunnel. Independent control of the needles and deflectors allows the deflectors to move rapidly in response to load changes while maintaining stable, controlled operation of the needles.

Needle Sequencing

L&S Electric's control algorithm includes needle sequencing, giving the governors independent control of the turbine's six needles. Needle sequencing allows operation of the turbine with fewer needles at lower loads, thus allowing the unit to operate more efficiently throughout the entire range of operation.

Needle sequencing is extremely difficult with a mechanical system because it requires the operator to manually link and unlink the nozzles. With a digital governor system that has individual needle control, needle sequencing becomes feasible and allows unit efficiency improvements by maximizing the power output for the amount of water required. For example, if only a third of the power is required, it is more efficient to operate a six-needle turbine with two needles at 100 percent flow rather than six needles at 33 percent flow.

Isochronous Loadsharing

In addition to needle sequencing, L&S Electric incorporated isochronous loadsharing into the control for the Tyee Lake plant. Isochronous loadsharing allows both of the units at the Tyee Lake plant to operate with zero droop while sharing load between them. The two units at Tyee Lake represent the majority of the generation for the system, so running these units in isochronous control eliminates steady state frequency deviations throughout the course of a day, thereby minimizing the time drift on the 60 hertz clocks connected to the system. Typically, only one unit can be operated on a system in isochronous control, and this unit absorbs all of the changes in load. This is termed the "swing unit." By operating two units in isochronous mode, each unit shares the changes in load, thus reducing the need for operator intervention to keep the unit away from either maximum or minimum generation.

The loadsharing feature allows the two units to share the system load requirements either equally, or with a predetermined offset between them. The offset prevents the two machines from going through needle transitions at the same time.

Water Waste Mode

A water waste mode also was incorporated into the control for the governors. Water wasting is a feature that allows the turbine to not only react well during load rejections, but also provide better frequency regulation during load acceptances. Typically, the timing of the needle servomotors is very slow, about 20 seconds for closing and 50 seconds for opening, to avoid tunnel, penstock and equipment damage. Thus, during an underspeed condition, the turbine is very slow to provide the additional capacity demanded by the system. The resulting underspeed condition can be limited by giving the turbine some spinning reserve so the needles don't have to move quickly to provide more power to the system. The needles are opened above the base load requirement, therefore opening the deflectors immediately applies more power to the unit and minimizes underfrequency conditions during load acceptance.

Underfrequency Detection

Two separate underfrequency criteria were set within the controller. If the controller senses that the system frequency meets either of these thresholds, the underfrequency detection system automatically places the governor into water wasting mode. This allows the unit to accept load as well as reject it rapidly, improving the frequency regulation. It also turns off needle sequencing, bringing all six needles into service, allowing the governor to add power more rapidly than under two- or four-needle operation.

Automatic Synchronizing

L&S Electric incorporated an automatic synchronizing algorithm into the design so the turbines could be put on line automatically. With the previous system, operators had to go through a number of manual procedures that required constant adjustment of the speed and voltage of the units to match the system. Now with the digital governor system, the PLC enables the operator to simply push a button. From there, the governor takes over and automatically matches the unit's frequency and voltage to that of the system. The automatic process takes out the risk that the operator is not correctly synchronizing the turbines and generators at the moment of breaker closure.

Choosing the Right Components

For L&S Electric, implementing these specialized control modes was facilitated by the Modicon Quantum PLCs and the Unity programming software. The Modicon Quantum PLC is customizable, flexible and capable of performing a multitude of operations. In addition, the non-proprietary Unity software is easy to use and gave L&S the ability to write its own function blocks to create a customized solution for FDPPA. L&S was able to reuse the function blocks and large sections of code, while feeling comfortable that there wouldn't be any problems. The products also gave the system integrator the ability to monitor and modify the control while the unit was running.

FDPPA didn't initially realize what a key factor the automated individual needle control was in the governor system. After seeing some of the processes in action, FDPPA realized how much the automated controls, especially needle sequencing and water wasting, simplified its operations while providing greatly improved performance. The agency was impressed with L&S Electric's ability to develop these complex control algorithms and to custom design control panels that fit into the small head pit areas above the turbines. The compact automation products allowed L&S to fit all the necessary components into a tight area.

GOING THE EXTRA MILE

Not only did FDPPA value the control algorithms provided by L&S Electric, but the agency also was impressed with the system integrator's willingness to go the extra mile. Essentially, L&S provided a turn-key project, hiring and supervising the mechanical and electrical contractors and even performing all of the demolition and installation engineering. L&S completed much of the engineering work up front to incorporate as much of the existing field wiring as possible. This reduced the amount of time in the field, shortened the installation time, and eliminated possibilities for errors because the engineers reused wires they knew were connected to the correct points. L&S also built and tested all the equipment at their plant in Wisconsin to ensure that it was wired, built and programmed correctly before shipping it to Alaska. After it was installed, L&S Electric tested everything again.

In addition, L&S Electric is an International Organization for Standardization (ISO) certified company. The entire integration process, including the mechanical, electrical and software design, as well manufacturing, factory testing and documentation, goes through a rigorous checks and balances process to ensure quality and customer satisfaction.

Perhaps L&S Electric's dedication to a proven control integration process was most evident during commissioning. Throughout the numerous system checks, the system did not experience a single failure. As a pre-emptive measure to achieve this result, L&S teamed with FDPPA's consultant, Electric Power

Systems, and the Thomas Bay Power Authority operating personnel, to develop thorough test procedures prior to arriving on site.

The commissioning process not only involved verifying that the governor was working properly, but L&S Electric also spent an extensive period of time generating information for Electric Power Systems to complete an easy-to-understand electrical model of the control system that was integrated with the overall system to ensure everything responded properly. Therefore, L&S spent extra time operating the units at various load levels and with induced disturbances to gather the needed data.

Even with such detailed and complex requirements, commissioning lasted only five days for the first unit and three days for the second. L&S Electric credits the speed of the process to the fact that the control algorithm used in the Tyee Lake project was similar to previous successful projects.

VALUE ADDED

FDPPA also appreciated the project team assembled by L&S Electric. One of its requirements for the job was that the project coordinator be extremely capable because there were many details to handle, and the plant's remote location and other logistical concerns compounded those needs. The agency appreciated the fact that L&S Electric assembled a project team with a dedicated project engineer and administrator who saw the project through from inception to completion.

A highly coordinated team was essential as the project required equipment to be shipped on barges, and only during high tide. Essentially, L&S Electric was at the mercy of the boat schedule because its equipment wouldn't get to the docks unless it was high tide. In addition, the project was a camp job, with the on-site L&S Electric personnel staying at a FDPPA-owned bunk house and arriving by boat or bush plane. Just to get from the island of Wrangell to the plant required clear weather and high tide. Overall, the logistics of simply moving people and equipment were complicated and required long-range planning and spot-on timing.

THE FUTURE

The residents of Wrangell and Petersburg have not experienced a single black out since the Tyee Lake operators gained familiarity with the new governors. The governors routinely manage load rejections of 2 to 4 MW. The new automated governing system has provided both towns with stability in their power system and reduced the nuisance factor of the power going out. Now, if a bird flies into a power line, there's a better chance the system won't go down; and if it does, operators at the hydro plant can re-energize the system much more quickly.

FDPPA expects Wrangell and Petersburg will save anywhere from $15,000 to $40,000 annually on diesel fuel costs. Although this figure is quite modest, the future value for the agency is in its ability to operate the Swan-Tyee Intertie. The transmission line is half finished with completion expected in 2009. The new governors will allow FDPPA to export power from Tyee Lake to the Swan Lake plant transmission line and the city of Ketchikan. The value of this power will be a net of $28 million in revenue over the next 30 years for FDPPA. The estimated avoided cost for Ketchikan in diesel fuel bills over the same period is approximately $135 million at today's prices. This cost also doesn't include the necessary investment

Ketchikan would have made in replacement diesel generators. More importantly, without the new governors, the Swan-Tyee Intertie wouldn't even be possible.

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ABOUT THE AUTHORS

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Terry Bauman is a senior controls engineer with L&S Electric, Inc. For over 20 years, Mr. Bauman has focused on control system solutions for hydroelectric turbines. He has over 15 years of experience related specifically to speed governing of impulse-type turbines, with considerable practical experience in needle sequencing. He received a bachelor's degree in computer engineering from Case Western Reserve University.